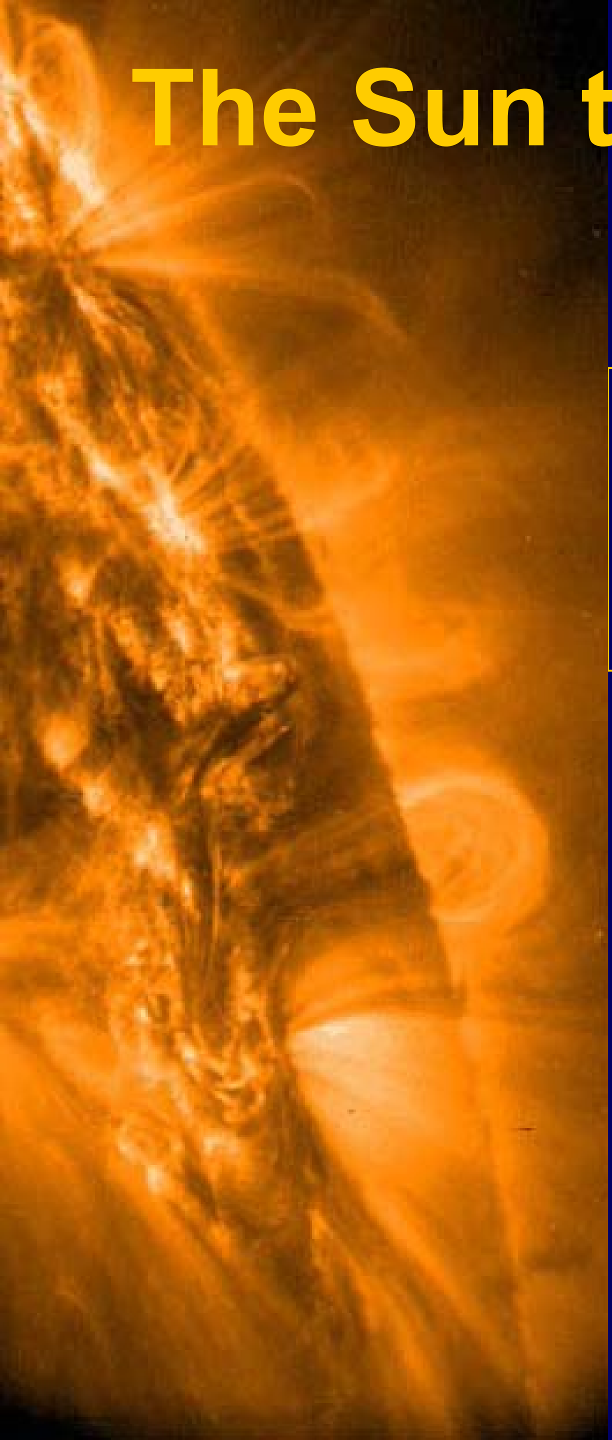
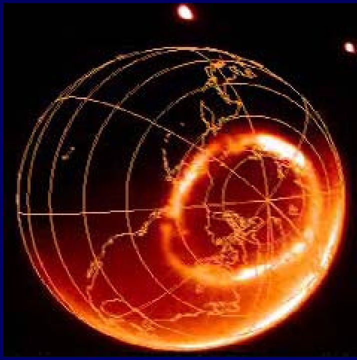
The Sun to the Earth – and Beyond

An Integrated Strategy for Solar and Space Physics, 2003-2013

Report of the
Solar and Space Physics Survey Committee
National Research Council
of the National Academies





Louis J. Lanzerotti
Chair, SSP Survey Committee

National Space Science and Technology Center
Huntsville, 21 November 2003

The Charge to the Survey Committee:

- Conduct a **BROADLY BASED ASSESSMENT** of the scientific priorities of U.S. solar and space physics research and operational programs. Consider contributions from all agencies (NASA, NSF, NOAA, DoD)

- Recommend **PRIORITIES** for the decade 2003-2013, including effective implementation of existing or planned programs.

- Recommend a **SYSTEMS APPROACH** to theoretical, ground-based, and space-based research that encompasses the flight programs and focused campaigns of NASA, the ground-based and basic research programs of NSF, and the complementary operational programs of other agencies such as DoD, DoE, and NOAA.

- Address the **HUMAN ASPECTS** of the field involving education, career opportunities, and public outreach.

- Suggest promising areas for the development of **NEW TECHNOLOGIES**.

Funding for the study was provided by
the following sponsors:

National Aeronautics and Space Administration

National Oceanic and Atmospheric Administration

National Science Foundation

United States Air Force Office of Scientific Research

Office of Naval Research

Key Features of the Study:

- **The Study is COMMUNITY-BASED**. The Survey Committee and Study Panels encouraged and enabled broad community involvement in the Study through a variety of means.

- **The Study is NATIONAL IN SCOPE**. The Study addresses the solar and space physics research activities of the NASA, NSF, NOAA, and DoD.

- **The Committee's recommendations include OPERATIONAL and TARGETED RESEARCH programs as well as BASIC RESEARCH programs**.

- **The recommended initiatives are consistent with a RESPONSIBLE AND REALISTIC RESOURCE ENVELOPE**.

Organization of the Study:

Outline of the Report:

Chapter 1: Scientific Milestones and Challenges

Chapter 2: Integrated Research Strategy for Solar and Space Physics

Chapter 3: Technology Challenges

Chapter 4: Connections between Solar and Space Physics and Other Disciplines

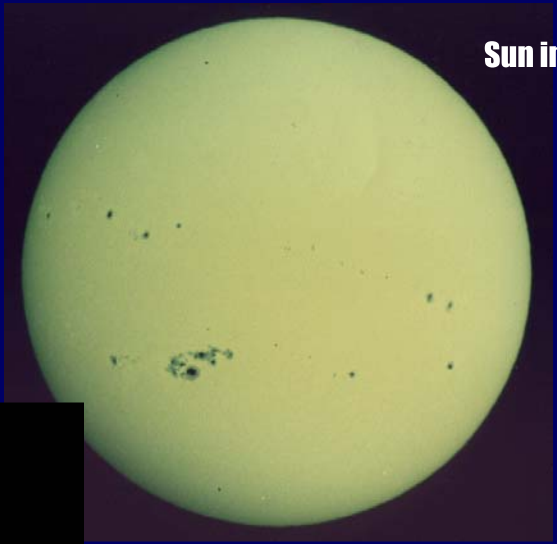
Chapter 5: Solar and Space Environment Effects on Technology and Society

Chapter 6: Education and Public Outreach

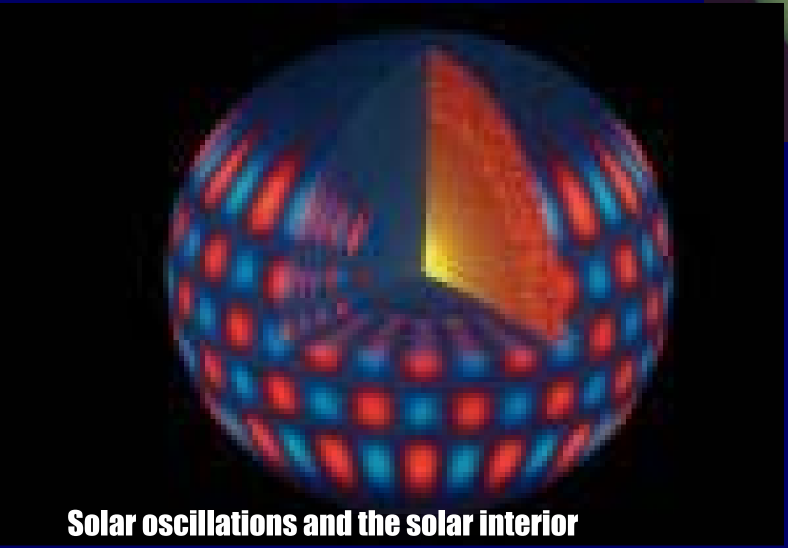
Chapter 7: Strengthening the Solar and Space Physics Research Enterprise

Scientific Challenges:

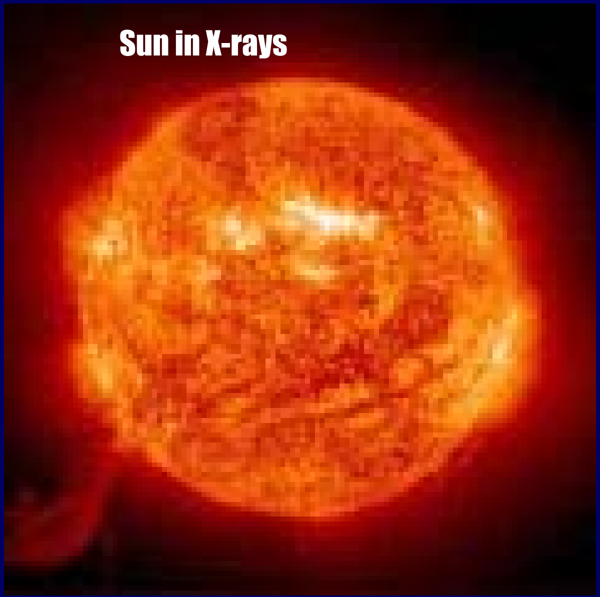
- **The Sun's Dynamic Interior and Corona:**
  Understanding the structure and dynamics of the Sun's interior, the generation of solar magnetic fields, the causes of solar activity and the origin of the solar cycle, and the structure and dynamics of the corona



Sun in white light



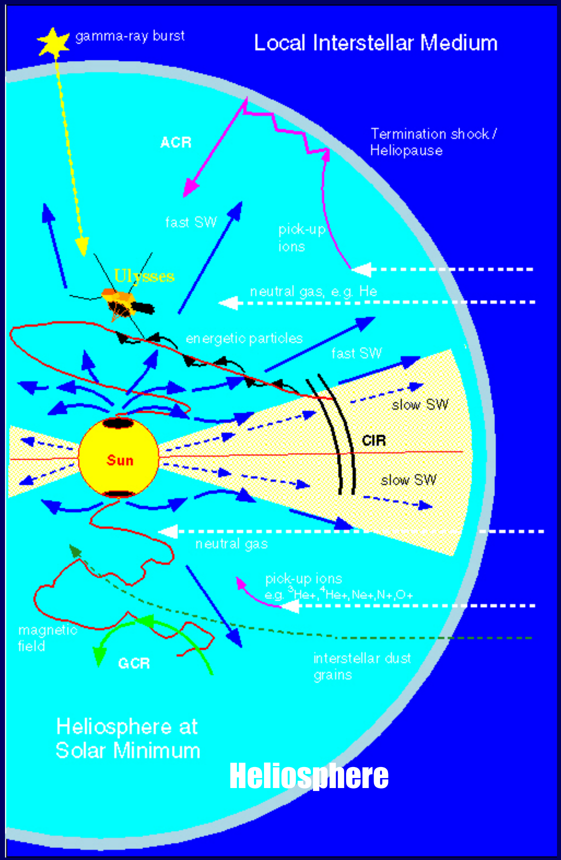
Solar oscillations and the solar interior

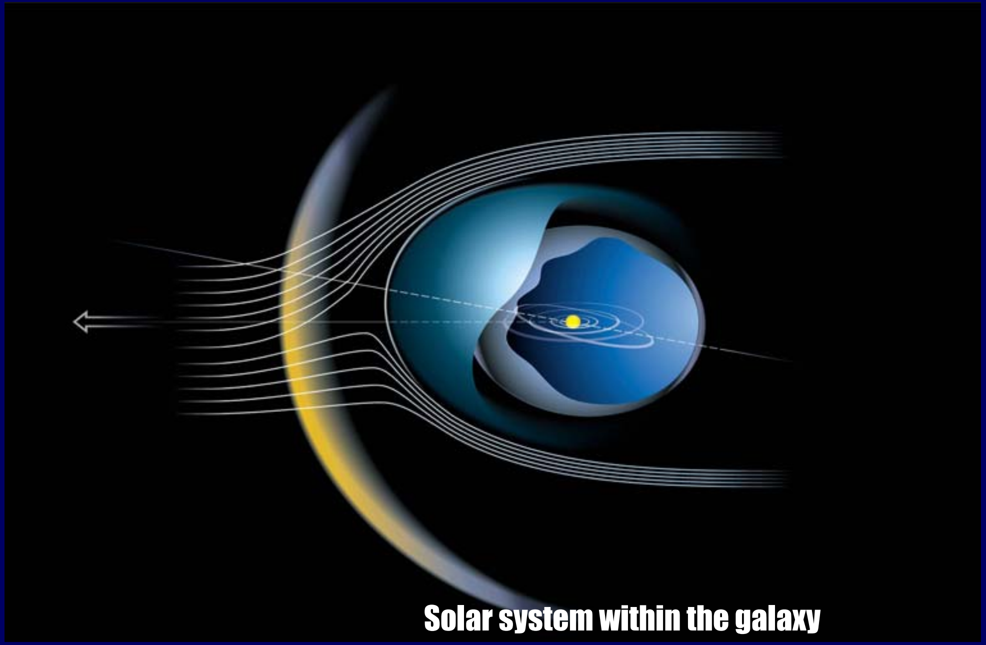


Sun in X-rays

Scientific Challenges:

- **The Sun's Dynamic Interior and Corona**
- **The Heliosphere and Its Components:**
  Understanding heliospheric structure, the distribution of magnetic fields and matter throughout the solar system, and the interaction of the solar atmosphere with the local interstellar medium





Scientific Challenges:

- **The Sun's Dynamic Interior and Corona**
- **The Heliosphere and Its Components**
- **The Space Environments of the Earth and Other Solar System Bodies:**
  Understanding the space environments of the Earth and other solar system bodies and their dynamical response to external and internal influences

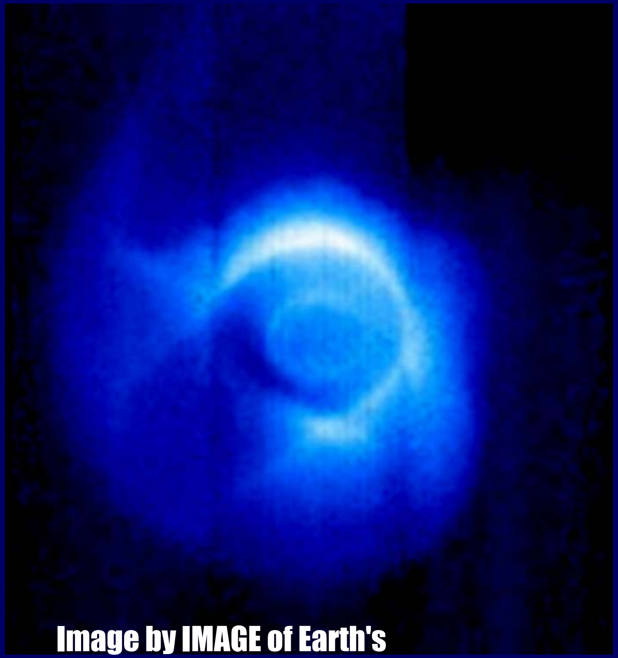
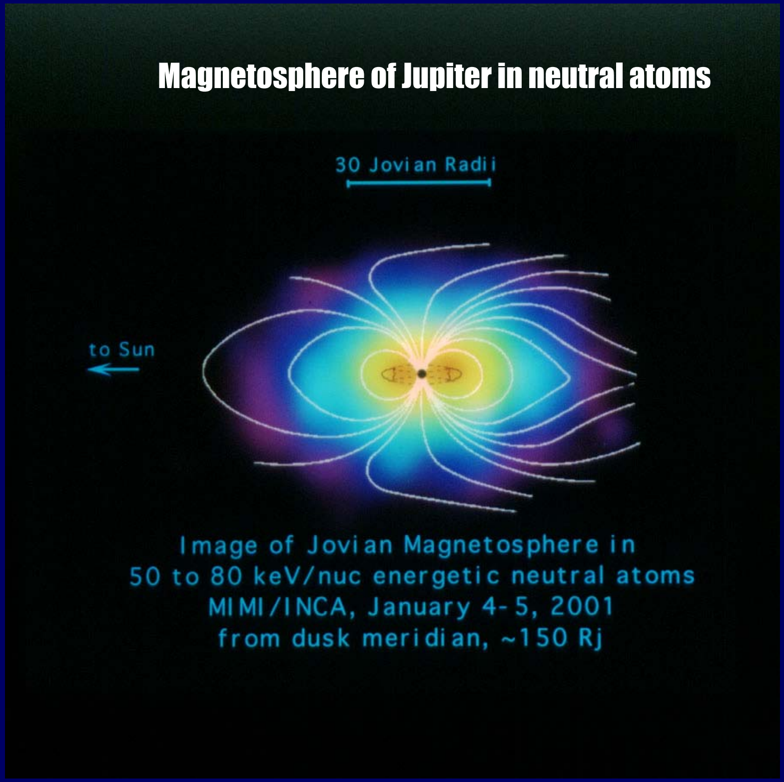


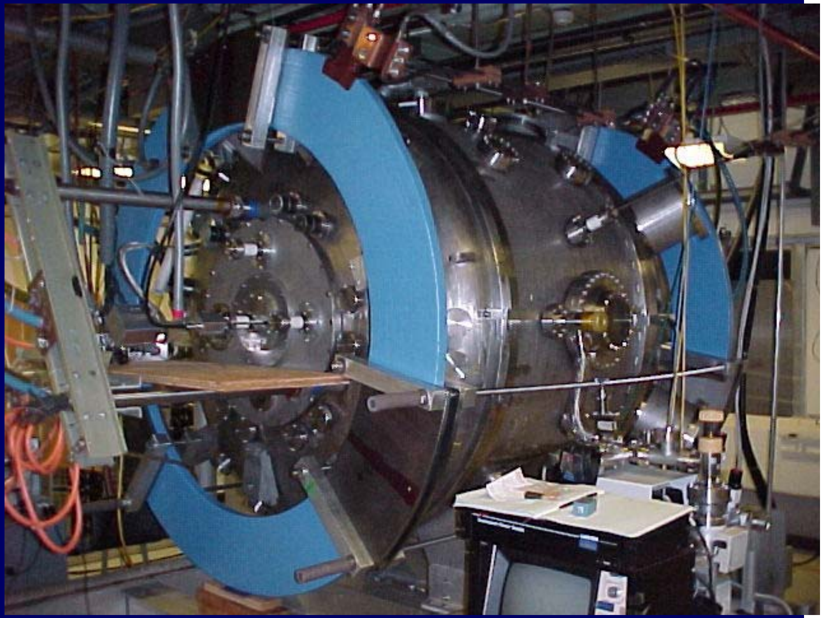
Image by IMAGE of Earth's Magnetosphere - EUV

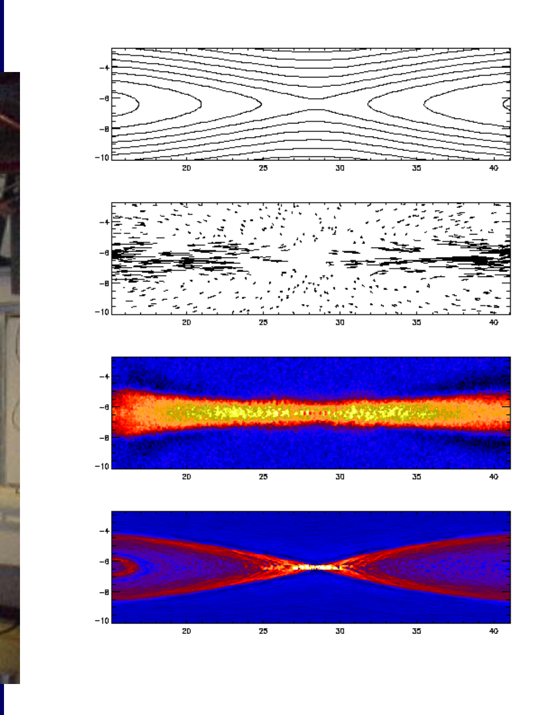


Scientific Challenges:

- **The Sun's Dynamic Interior and Corona**
- **The Heliosphere and Its Components**
- **The Space Environments of the Earth and Other Solar System Bodies**
- **Fundamental Space Plasma Physics:**
  Understanding the basic physical principles manifest in processes observed in solar and space plasmas

MRX,
PPPL



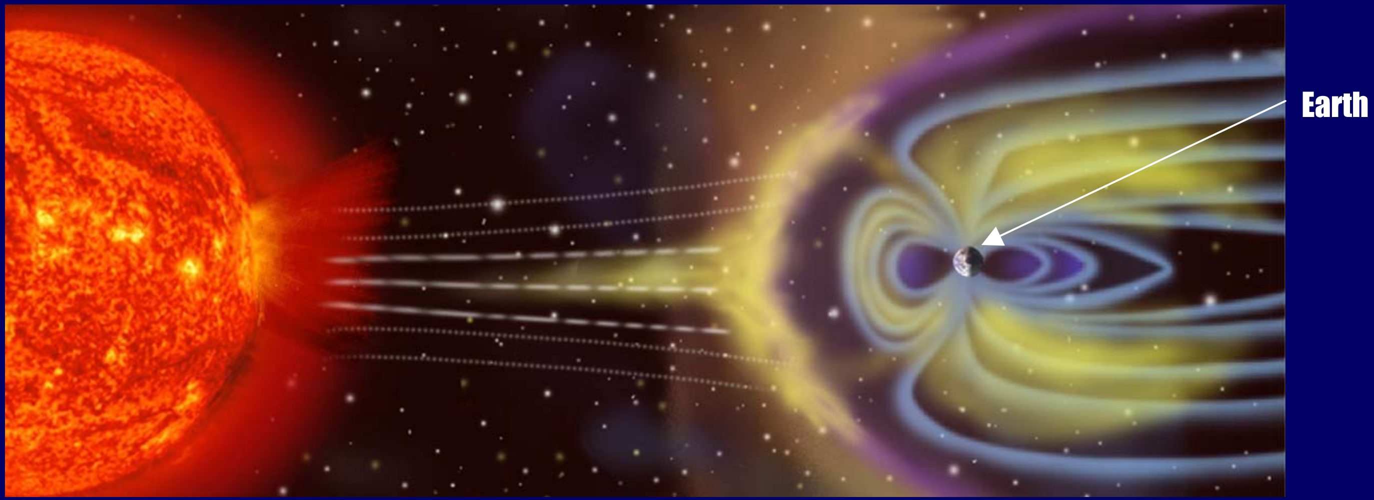


Drake,
modeling
reconnection

Scientific Challenges:

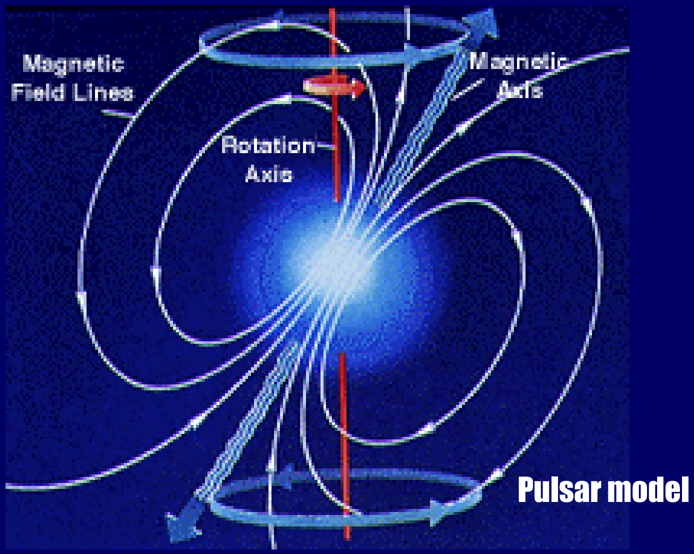
- **The Sun's Dynamic Interior and Corona**
- **The Heliosphere and Its Components**
- **The Space Environments of the Earth and Other Solar System Bodies**
- **Fundamental Space Plasma Physics**
- **Space Weather:**

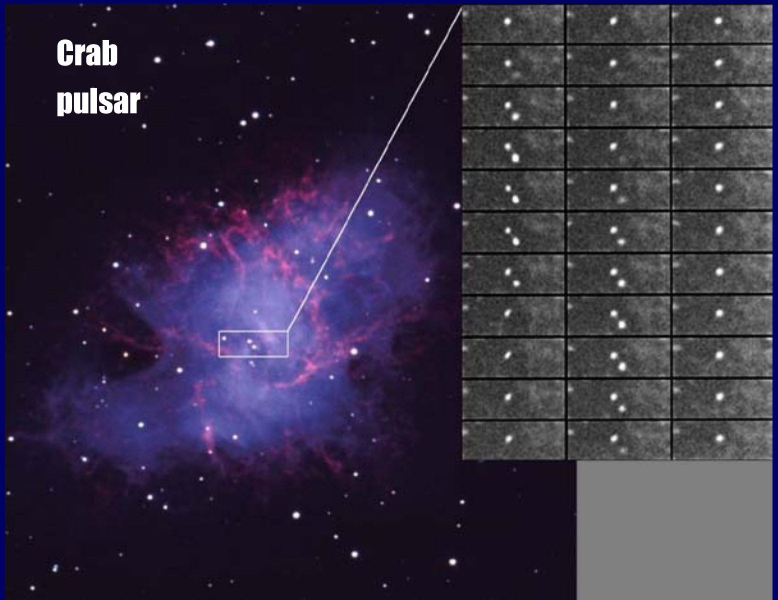
  Developing near real-time predictive capability for understanding and quantifying the impact on human activities of dynamical processes at the Sun, in the interplanetary medium, and in the Earth's magnetosphere



Scientific Challenges:

- **The Sun's Dynamic Interior and Corona**
- **The Heliosphere and Its Components**
- **The Space Environments of the Earth and Other Solar System Bodies**
- **Fundamental Space Plasma Physics**
- **Space Weather**
- **The Astrophysical Context:**
  Understanding the Sun, heliosphere, and planetary magnetospheres and ionospheres as astrophysical objects and in an astrophysical context





Prioritization Criteria:

- **Scientific Merit**

  Importance of scientific problems to be addressed: major frontier or incremental? Impact on other disciplines

- **Contribution to National Goals**

  Impact on space weather prediction and protection; education; commerce and industry; public awareness; national image

- **Programmatic Aspects**

  Technological readiness (amount of technological development required prior to possible implementation; risk assessments)

  Adequate theoretical foundation (is enough known to formulate the questions whose answers would definitively solve the problem?)

  Timing (e.g., with respect to synergistic or precursor programs)

  Total run-out costs

Program Categories:

Large: > $400M

Moderate: $250M - $400M

Small: < $250M

Vitality: Essential research infrastructure matters

Large and Moderate Programs:

Type of Program	Rank	Program	Description
Large	**1**	**Solar Probe**	Spacecraft to study the heating and acceleration of the solar wind through in situ measurements and some remote-sensing observations during one or more passes through the innermost region of the heliosphere (from ~0.3 AU to as close as 3 solar radii above the SunÕs surface).
Moderate	**1**	**Magnetospheric Multiscale**	Four-spacecraft cluster to investigate magnetic reconnection, particle acceleration, and turbulence in magnetospheric boundary regions.
	2	**Geospace Network**	Two radiation-belt mapping spacecraft and two ionospheric mapping spacecraft to determine the global response of geospace to solar storms.
	3	**Jupiter Polar Mission**	Polar-orbiting spacecraft to image the aurora, determine the electrodynamic properties of the Io flux tube, and identify magnetosphere-ionosphere coupling processes.
	4	**Multispacecraft Heliospheric Mission**	Four or more spacecraft with large separations in the ecliptic plane to determine the spatial structure and temporal evolution of CMEs and other solar-wind disturbances in the inner heliosphere.
	5	**Geospace Electrodynamic Connections**	Three to four spacecraft with propulsion for low-altitude excursions to investigate the coupling among the magnetosphere, the ionosphere, and the upper atmosphere.
	6	**Suborbital Program**	Sounding rockets, balloons, and aircraft to perform targeted studies of solar and space physics phenomena with advanced instrumentation.
	7	**Magnetospheric Constellation**	Fifty to a hundred nanosatellites to create dynamic images of magnetic fields and charged particles in the near magnetic tail of Earth.
	8	**Solar Wind Sentinels**	Three spacecraft with solar sails positioned at 0.98 AU to provide earlier warning than L1 monitors and to measure the spatial and temporal structure of CMEs, shocks, and solar-wind streams.
	9	**Stereo Magnetospheric Imager**	Two spacecraft providing stereo imaging of the plasmasphere, ring current, and radiation belts, along with multispectral imaging of the aurora.

Solar Probe

Solar Probe will make the first in-situ measurements inside 0.3 AU, the innermost region of the heliosphere and the birthplace of the heliosphere itself.

(Schedule determined by funding availability)

Objectives:

- Locate the source and trace the flow of energy that heats the corona
- Determine the acceleration processes and find the source regions of the fast and slow solar wind
- Identify the source regions and acceleration mechanisms for solar energetic particles
- Determine how the plasma, energetic particles, magnetic field, and waves evolve within the innermost heliosphere

Large and Moderate Programs:

Type of Program	Rank	Program	Description
Moderate	1	Magnetospheric Multiscale	Four-spacecraft cluster to investigate magnetic reconnection, particle acceleration, and turbulence in magnetospheric boundary regions.
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	5	Geospace	Three to fo investigate er atm
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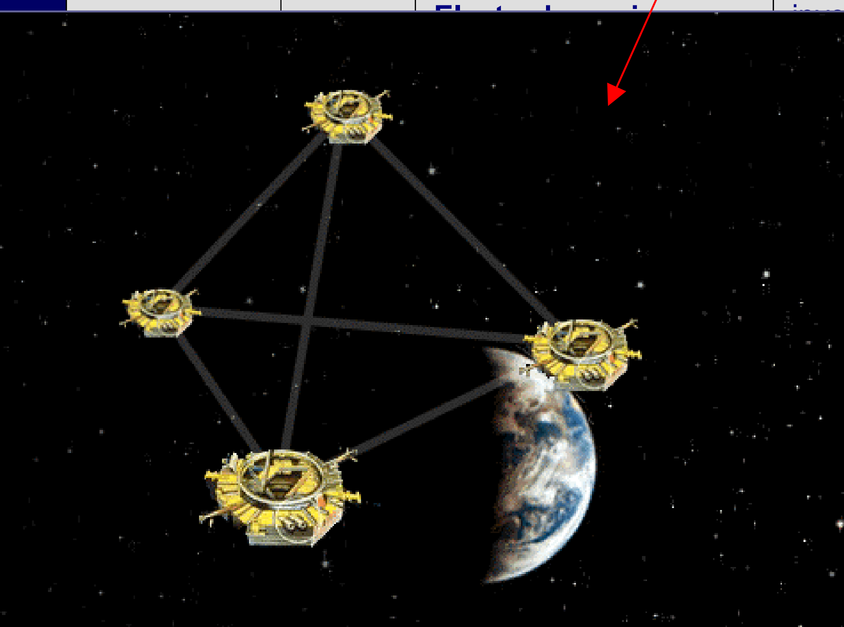
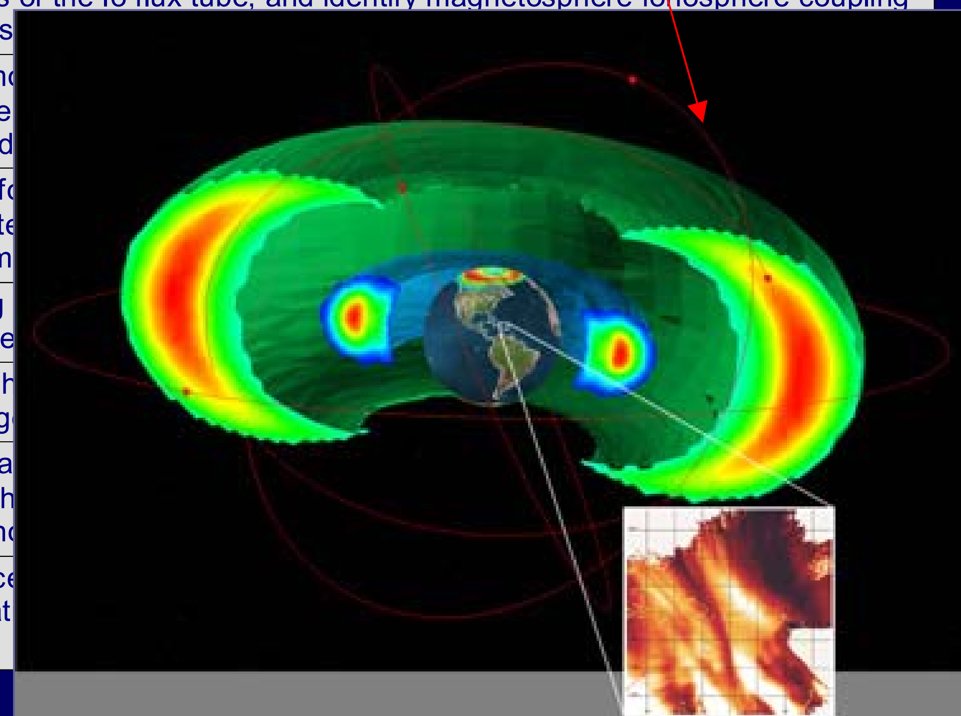
			space radiat





Large and Moderate Programs:

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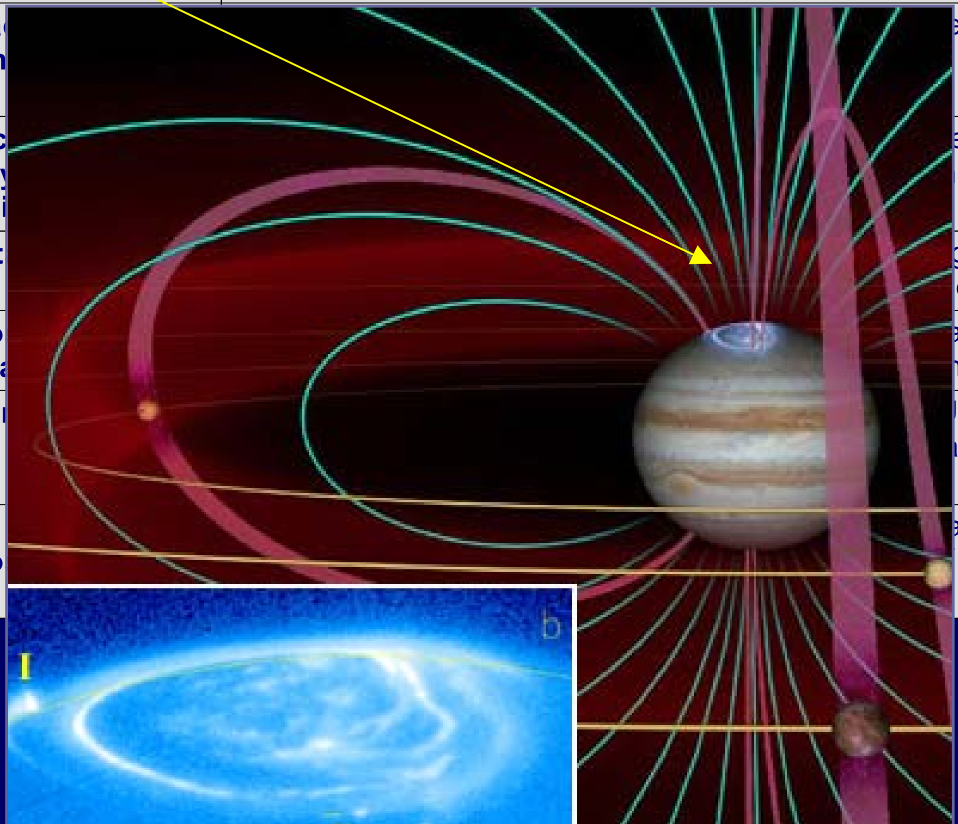
	3	**Jupiter Polar Mission**	Polar-orbiting spacecraft to image the aurora, determine the electrodynamic properties of the Io flux tube, and identify magnetosphere-ionosphere coupling processes.
	4	**Multispa Heliosph**	ecliptic plane to of CMEs and other
	5	**Geospac Electrody Connecti**	e excursions to e ionosphere, and the
	6	**Suborbit**	geted studies of solar entation.
	7	**Magneto Constella**	ages of magnetic fields n.
	8	**Solar Wi**	to provide earlier nd temporal structure of
	9	**Stereo Magneto Imager**	asphere, ring current, the aurora.



How Programs Map to Challenges:

	SCIENTIFIC CHALLENGES				
MISSIONS AND FACILITIES	***The Dynamic Solar Interior and Corona***	***The Heliosphere and Its Components***	***Earth and Planetary Space Environments***	***Fundamental Space Plasma Physics***	***Space Weather***
Solar Probe					
GEC					
Geospace Network					
Jupiter Polar Mission					
MMS					
Magnetospheric Constellation					
Multi-spacecraft Heliospheric Mission					
Solar Wind Sentinels					
Stereo Magnetospheric Imager					
Suborbital Program					

Cost Estimates/Technical Concerns:

Program	Cost (FY 2002 $M)	Technical Concern
Solar Probe	650	Moderate to High
GEC	300	Low
Geospace Network	400	Low
Jupiter Polar Mission	350	Moderate
Magnetospheric Multiscale	350	Low
Magnetospheric Constellation	325	High
Multi-Heliospheric Probes	300	Moderate
Solar Wind Sentinels	300	Moderate
Stereo Magnetospheric Imager	300	Low
Suborbital Program	30/yr (2002) - 60/yr (2012)	Low
Frequency Agile Solar Radio Telescope	60	Low
L1 Monitor	100	Low
Advanced Modular ISR	65	Low
Small Instrument Distributed Ground Network	5/yr	Low
Solar Orbiter	100	Moderate
UNEX	35/yr	Moderate

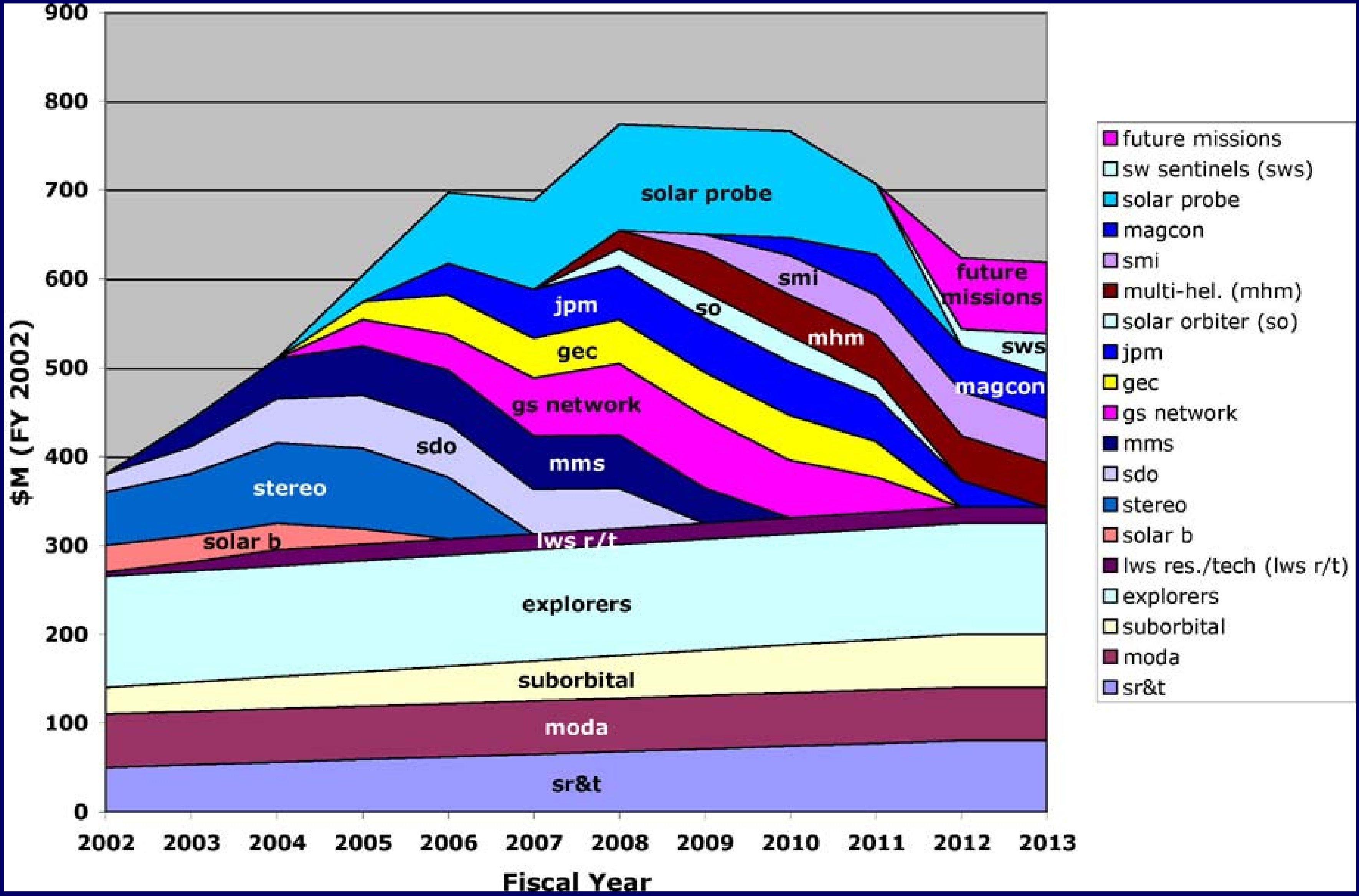
Deferred High-Priority Flight Missions:

The Survey Committee gave high priority to several initiatives recommended by the Panels but did not include them in the integrated program because of the overall budget constraint, mission sequencing requirements, or technical readiness issues.

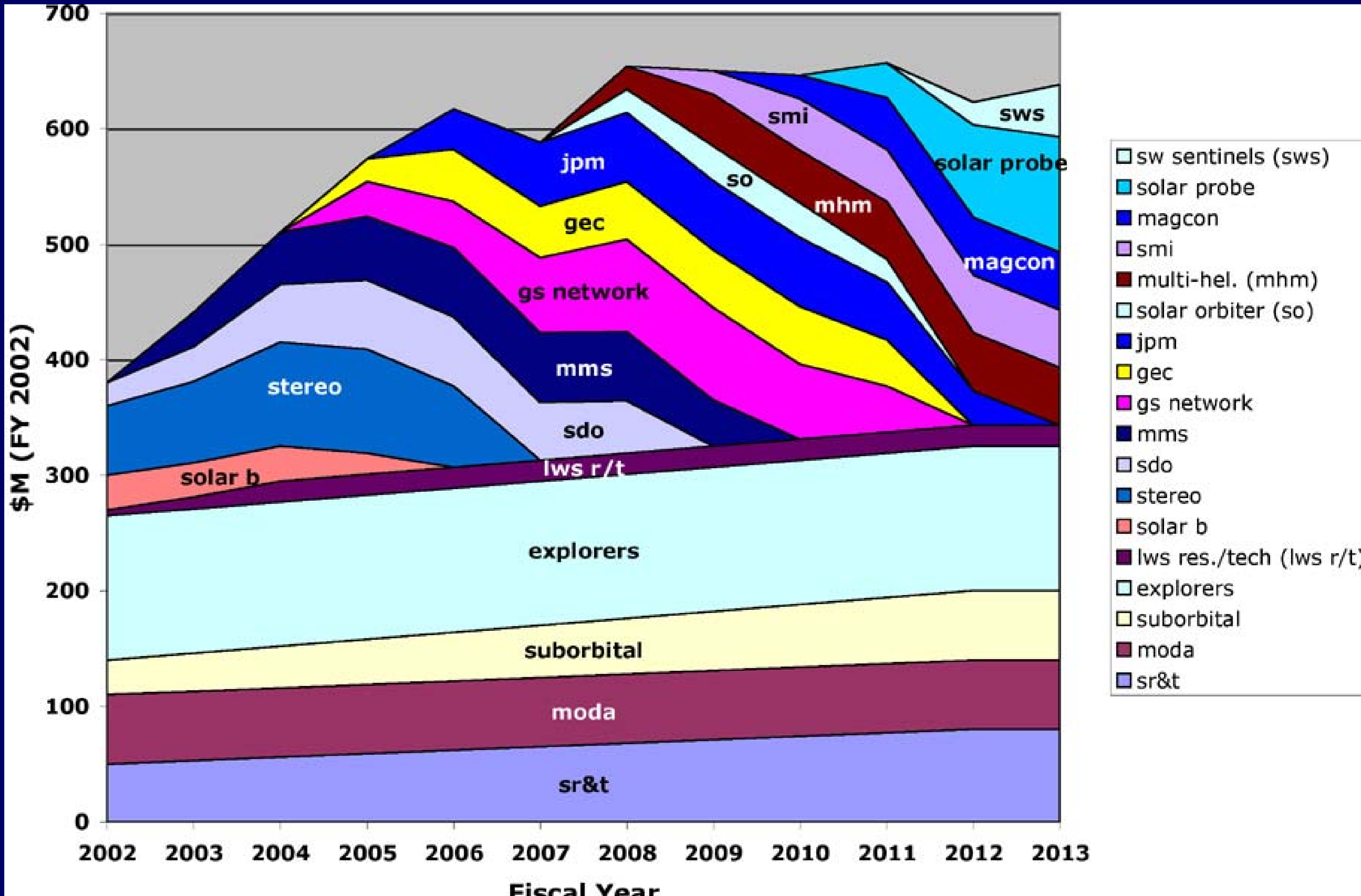
Mission	Reason for Deferral
Large	
Interstellar Probe	Advanced Propulsion Technology Needed
Moderate	
Auroral Cluster	Lower Priority Than Other Moderate Missions
Dayside Boundary Constellation	Next Step After Magnetospheric Constellation
Geospace System Response Imagers	Advanced Solar Sail Technology Needed
Io Electrodynamics	Next Step After Jupiter Polar Mission
Mars Aeronomy Probe	Not Supported by Existing SEC Mission Lines
Reconnection and Microscale Probe	Lower Priority Than Other Moderate Missions
Venus Aeronomy Probe	Not Supported by Existing SEC Mission Lines

Note: the listing above is in alphabetical and not priority order.

NASA Mission Costs 1: (Solar Probe Starts in '03)

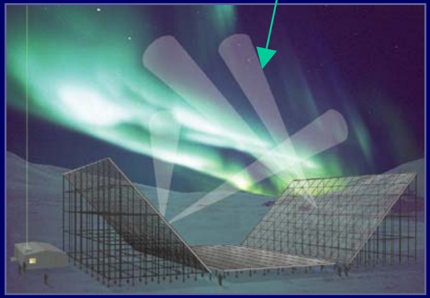


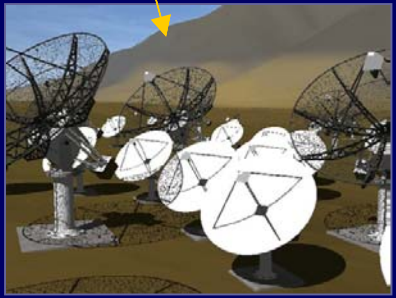
NASA Mission Costs 2: (Solar Probe Starts in '09)

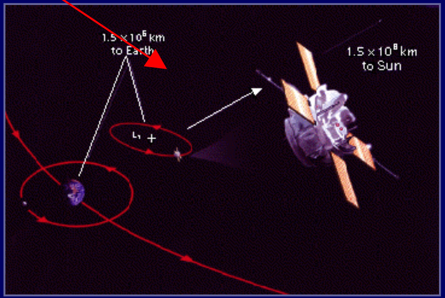


Small Programs:

Rank	Program	Description
1	**Frequency Agile Solar Radio Telescope**	Wide frequency-range (0.3 – 30 Ghz) radio telescope for imaging of solar features from a few hundred km above the visible surface to high in the corona.
2	**Advanced Modular Incoherent Scatter Radar**	Movable incoherent scatter radar with supporting optical and other ground-based instruments for continuous measurements of magnetosphere-ionosphere interactions.
3	**L1 Monitor**	Continuation of solar-wind and interplanetary magnetic field monitoring for support of Earth-orbiting space physics missions. Recommended for implementation by **NOAA.**
4	**Solar Orbiter**	U.S. instrument contributions to ESA spacecraft that periodically co-rotates with the Sun at 45 solar radii to investigate the magnetic structure and evolution of the solar corona.
5	**Small Instrument Distributed Ground Network**	NSF program to provide global-scale ionospheric and upper atmospheric measurements for input to global physics-based models.
6	**UNEX**	Revitalization of university-class Explorer program for more frequent access to space for focused research projects.







How Programs Map to Challenges:

	SCIENTIFIC CHALLENGES				
MISSIONS AND FACILITIES	***The Dynamic Solar Interior and Corona***	***The Heliosphere and Its Components***	***Earth and Planetary Space Environments***	***Fundamental Space Plasma Physics***	***Space Weather***
Frequency Agile Solar Radio Telescope					
Advanced Modular Incoherent Scatter Radar					
L1 Monitor					
Solar Orbiter					
Small Instr. Distributed Ground-based Network					
University Explorers					
Solar Dynamics* Observatory					
Advanced* Technology Solar Telescope					

*planned or approved initiatives

Cost Estimates/Technical Concerns:

Program	Cost (FY 2002 $M)	Technical Concern
Solar Probe	650	Moderate to High
GEC	300	Low
Geospace Network	400	Low
Jupiter Polar Mission	350	Moderate
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Solar Orbiter	100	Moderate
UNEX	35/yr	Moderate

Vitality Programs:

Rank	Program	Description
1	**NASA SR&T**	NASA research and analysis program.
2	**National Space Weather Program**	Multi-agency program led by the NSF to support focused activities to improve scientific understanding of geospace in order to provide better specifications and predictions.
3	**Coupling Complexity**	NASA/NSF Theory and modeling program to address multi-process coupling, nonlinearity, and multi-scale and multi-regional feedback.
4	**Solar and Space Physics Information System**	Multi-agency program for integration of multiple data sets and models in a system accessible by the entire solar and space physics community.
5	**Guest Investigator Program**	NASA program for broadening the participation of solar and space physicists in space missions.
6	**Sun-Earth Connection Theory and LWS Data Analysis, Theory, and Modeling Programs**	NASA program to provide long-term support to critical-mass groups involved in specific areas of basic and targeted basic research.
7	**Virtual Sun**	Multi-agency program to provide a systems-oriented approach to theory, modeling, and simulation that will ultimately provide continuous models from the solar interior to the outer heliosphere.

Vitality Programs:

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1	**NASA SR&T**	NASA research and analysis program.
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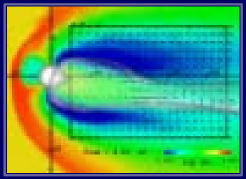
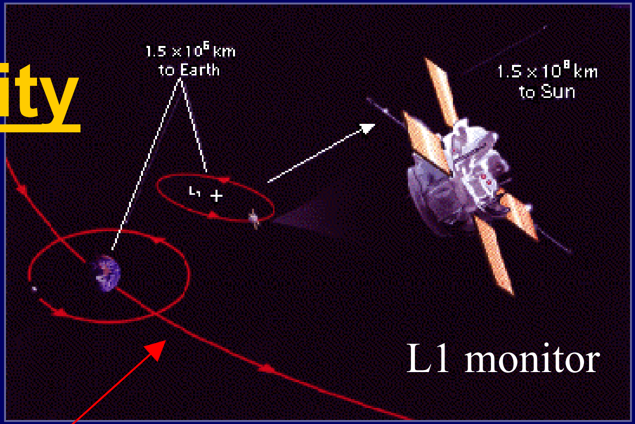
Coupling complexity in space plasma systems



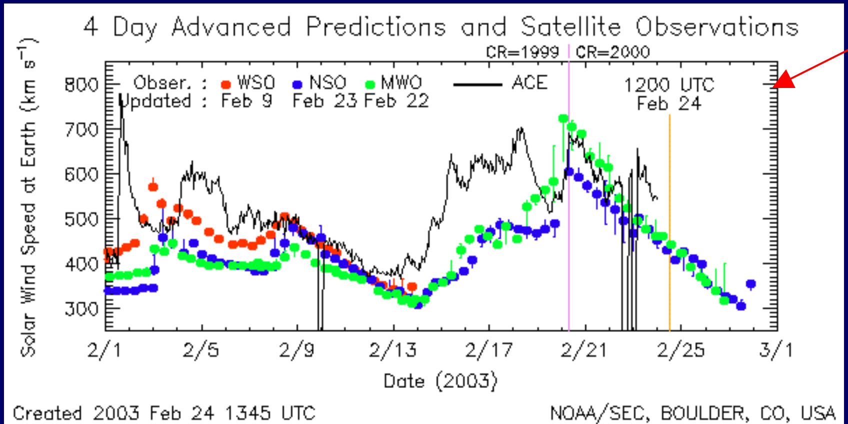
or, equivalently

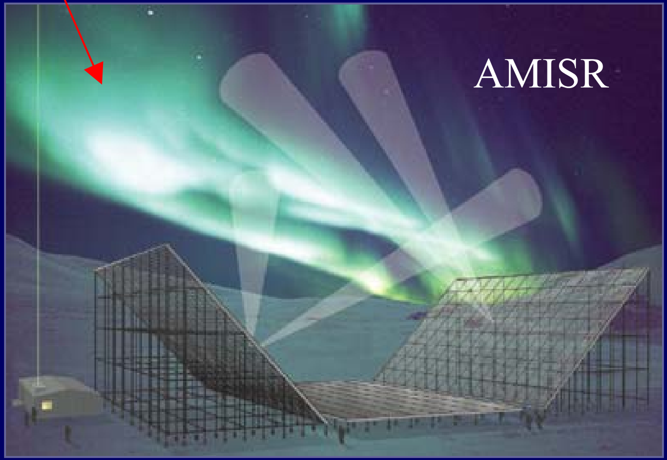
The science of nonlinearity, multi-scale, and multi-process feedback in space plasma systems

Challenges of Coupling Complexity



1. Formulation of sophisticated models that incorporate disparate scales, processes, and regions, the development of analytic theory, and maintaining a strong connection to basic science
2. Computation
3. Incorporation of coupling complexity into space physics models
4. Integrating theory, modeling, and space- and ground-based observations
5. Data exploration and assimilation
6. Transition of scientific models to operational status in, e.g., space weather activities





Technology Development:

Traveling to the Planets and Beyond

Recommendation: NASA should assign high priority to the development of advanced propulsion and power technologies required for the exploration of the outer planets, inner and outer heliosphere, and local interstellar medium.

Advanced Spacecraft Systems

Recommendation: NASA should continue to give high priority to the development and testing of advanced spacecraft technologies through such programs as the New Millennium Program and its advanced technology programs.

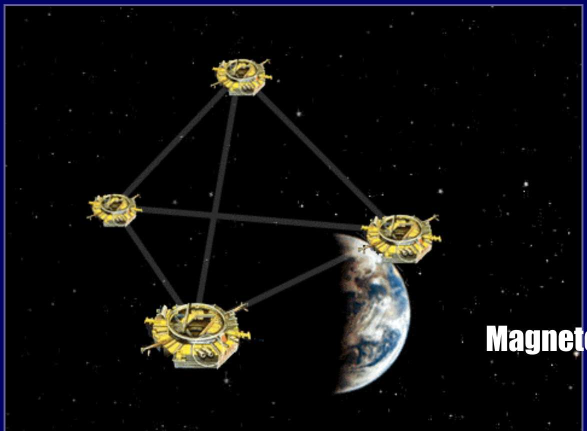
Solar sail

Advanced Science Instrumentation

Recommendation: NASA should continue to assign high priority, through its newly established instrument development programs, to supporting the development of advanced instrumentation for solar

Gathering and Assimilating Data from Multiple Platforms

Recommendation: NASA should accelerate the development of command and control and data acquisition technologies for constellation missions



Magnetosphere multiscale

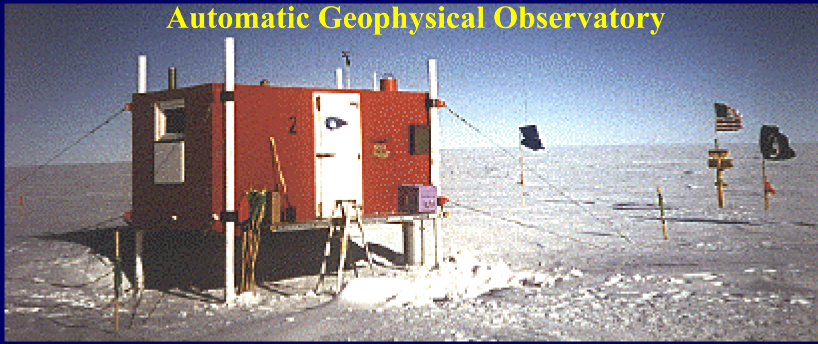
Technology Development:

Modeling the space envirnoment

Recommendation: Existing NOAA and NASA facilities should be expanded to accommodate the large scale integration of space- and ground-based data sets into physics-based models of the geospace environment

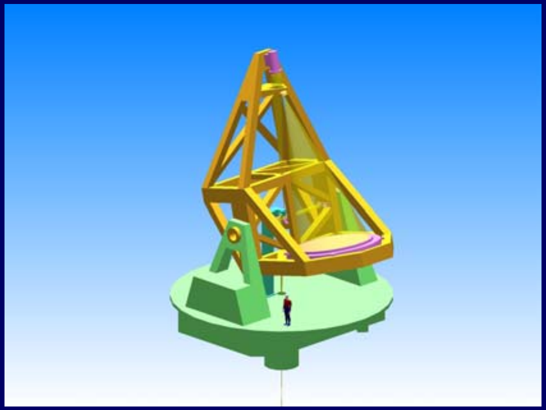
Observing Geospace from Earth

Recommendation: The relevant program ofices in the NSF should support comprehensive new approaches to the design and maintenance of ground-based, distributed instrument networks, with proper regard for the severe environments in which they must operate



Observing the Sun at high spatial resolution

Recommendation: The NSF should continue to fund the technology development for the Advanced Technology Solar Telescope (ATST)



4-m aperture, integrated adaptive optics, low scattered light, infrared coverage

Solar and Space Environment Effects on Technology and Society

Challenge 1: Developing processes and policies for the monitoring of the space weather environment

Challenge 2: Determining those research instruments and observations that are required to provide the basic modeling interactions of the solar-terrestrial environment with technical systems and for making sound technical decisions

Challenge 3: Establishing, maintaining , and evolving mechanisms for the efficient transfer of new models of the solar-terrestrial environment into the user community

Challenge 4: Assessing the capability for predicting the solar-terrestrial impact on specific technological systems as well as for predicting space weather in general and improving this capability as needed

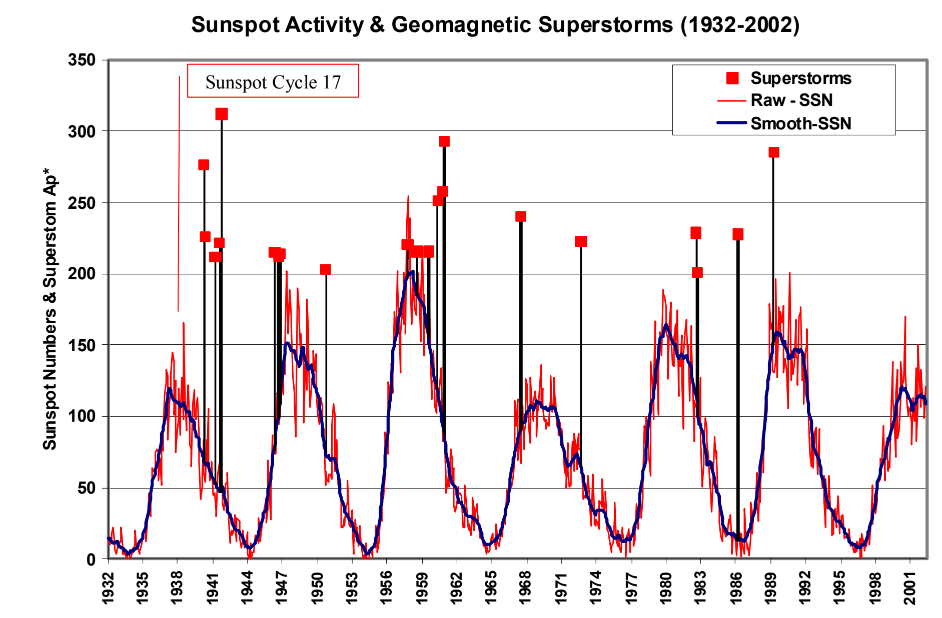
Challenge 5: Determining the appropriate roles for the public and the private sectors in acquiring, assessing, and disseminating information and models related to the solar-terrestrial environment in the context of its relevance for technological systems

Effects on Technology and Society:

***Challenge 4*: Assessing the capability for predicting the solar-terrestrial impact on specific technological systems as well as for predicting space weather in general and improving this capability as needed.**

Recommendation: The DOD and NOAA should be the lead agencies in the acquisition of data sets required for accurate specification and forecast modeling, including data from the international community. Because it is extremely important to have real-time data, both space- and ground-based, for predictive purposes, NOAA and DOD should invest in new ways to acquire real-time data from all those ground- and space-based sources available to them. All data acquired should contain error estimates, which are required by data assimilation models.

Recommendation: A new centralized database of extreme space weather conditions should be created that covers as many of the relevant space weather parameters as possible.



Geomagnetic superstorms
Metatech Corp.

Education and Public Outreach:

Solar and Space Physics in Colleges and Universities

Recommendation: The NSF and NASA should jointly establish a program of "bridged positions" that provides (through a comp etitive process) partial salary, startup funding, and research support for four new faculty members per year for 5 years.

Distance Education

Recommendation: The NSF and NASA should jointly support an initiative that provides increased opportunities for distance education in solar and space physics.

Undergraduate Research Opportunities

Recommendation: NASA should institute a specific program for the support of undergraduate research in solar and space physics at colleges and universities. The program should have the flexibility to support such research either as a supplement to existing grants or as a stand-alone grant program.

Recommendation: Over the next decade NASA and the NSF should fund several resource development groups to develop solar and space physics educational resources (especially at the undergraduate level), to disseminate those resources, and to provide training for educators and scientists in the effective use of such resources.

Strengthening the SSP Research Enterprise:

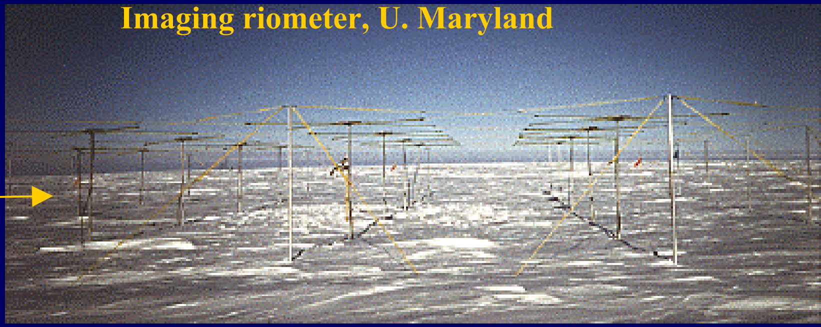
Strengthening the Solar and Space Physics Community

Recommendation: NASA should undertake an independent outside review of its existing policies and approaches regarding the support of solar and space physics research in academic institutions, with the objective of enabling the nation's colleges and universities to be stronger contributors to this research field.

Recommendation: NSF-funded national facilities for solar and space physics research should have resources allocated so that the facilities can be widely available to outside users

Cost-Effective Use of Existing Resources

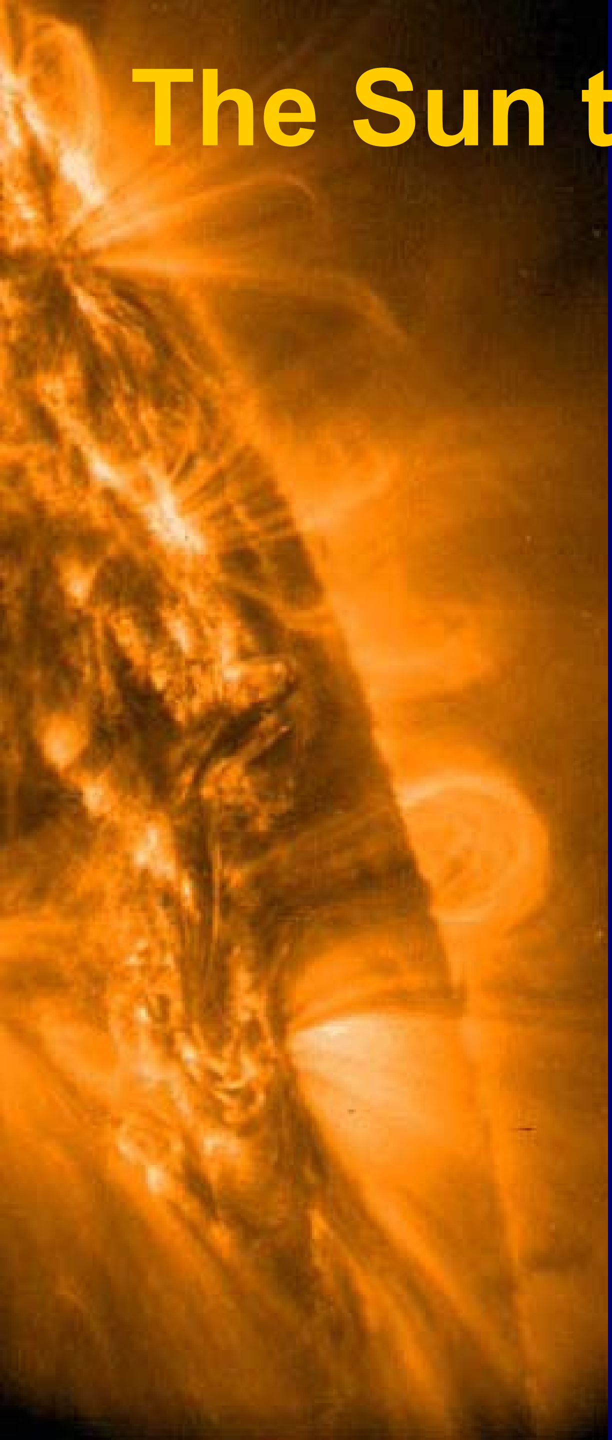
Recommendation: The NSF and NASA should give all possible consideration to capitalizing on the availability of existing ground- and space-based assets as the goals of new research programs are defined



Access to Space

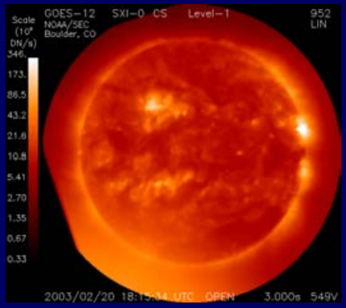
Recommendation: NASA should revitalize the Suborbital program to bring the flight opportunities back to previous levels.

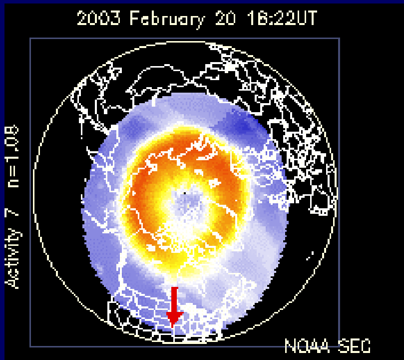
Recommendation: The scientific objectives of the *NASA Discovery Program* should be expanded to include those frontier space plasma physics research subjects that could not otherwise be accommodated by other spacecraft opportunities.



The Sun to the Earth – and Beyond

An Integrated Strategy for Solar and Space Physics, 2003-2013





SUMMARY

The integrated strategy developed by the Decadal Survey presents a challenging research and operational program in solar and space physics for the next decade, a program that is directed toward the highest priority objectives, is technically feasible, and is within estimated budgetary guidelines.